Reliable, Low Cost Distributed Generator/Utility System Interconnect

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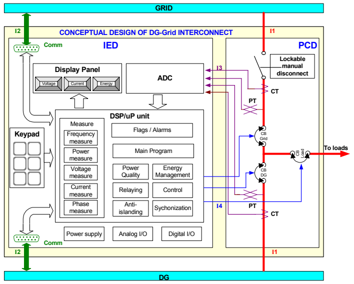
Program Objectives: **Explore technical issues associated with interconnecting Distributed Generation (DG) with Electric Power Systems.**
Develop a Universal Interconnect (UI) system to bridge the technical barriers and facilitate the interconnection of DG.

UI Study and Design

UI Conceptual Design



GRID
CONCEPTUAL DESIGN OF DG-Grid INTERCONNECT
IED
PCD
Comm
Display Panel
ADC
Lockable manual disconnect
CT
PT
Keypad
DSP/uP unit
Flags / Alarms
Main Program
Relaying
Control
Anti-islanding
Sychonization
Power supply
Analog I/O
Digital I/O
To loads
DG

Key Features:

- **Modularity:**
  IED (Intelligent Electronic Device) , **PCD** (Power Carrying Device)
- **Standardized Interfaces: Power(I1), Communication(I2), Sensor(I3), Control(I4)**
- **Technology neutral, suitable for Fuel Cell, Microturbine, Genset, etc.**
- **Pre-testing and pre-certification for 1547 compliance**
- **Universal platform with natural progression of functionality**
  - **Local Protection (P1547 functions): U/O V&F, Sync check, AI, etc.**
  - **Local Control: V&F support, Power quality, etc.**
  - **Coordinated Protection/Control: Dispatch, EMS, etc.**

IEEE P1547 Compliance Matrix

4.1	***General Requirements***		
4.1.1	Voltage Regulation	Available	P1547 says that DG shall not actively regulate the voltage at the PCC. UI should monitor the voltage to be within the range of ANSI C84.1, Range A. G60 has voltage protection, monitoring, and data log
4.1.2	Integration with Area EPS Grounding	Available	need to consider different Transformer connections, e.g. Wye/Wye, Delta/Wye, etc. will require different protection elements. In some cases, it may need to sense primary (substation) voltage and require communications. G60 has elements for grounding protection
4.1.3	Synchronization	N/A	within +/-5% prevailing voltage level, monitor flicker effect. Flicker monitoring is not the current G60 function. G60 has sync check.
4.1.4	Distributed Resources on Distribution Secondary Grid and Spot Networks	N/A	Reverse power protection is needed to coordinate with netowrk protectors. Unclear to exactly define UI functions as the issue is not thoroughly addressed in the current standard version.
4.1.5	Inadvertent Energization of the Area EPS	Available	dead circuit check
4.1.6	Monitoring Provisions	Available	This function refers to remote monitoring by utilities operators. Therefore, communication is needed. How to communicate, however, is undertermined. P1547.3 will address communication requirements. G60 has communication capabilities. The requirement will be determined by local power control operator.
4.1.7	Isolation Device	N/A	External to UI Box. readily accessible, lockable, visible-break isolation device. It may be desirable for UI to monitor (but not control) the status of the isolation device.
4.1.8	Interconnect Integrity		
4.1.8.1	Protection from Electromanetic Interference (EMI)	Available	UI IED device meets the requirement
4.1.8.2	Surge Withstand Performance	Available	UI IED device meets the requirement
4.1.8.3	Paralleling Device	N/A	contact/CB ratings (220% of the rated voltage), not part of IED

4.2	***Response to Area EPS Abnormal conditions***		
4.2.1	Area EPS Faults	Available	G60 has some elements for fault detection
4.2.2	Area EPS Reclosing Coordination	*Anti-Islanding protection*	reclosing time varies, e.g. reclosing due to lightning is normally fast (less than 0.5s), however, reclosing due to tree fall is normally slow (up to 10s). Different utilities set the reclosing time differently, depending on their practical conditions. Therefore, the timing of AI protection should be adjustable to coordinate with recloser settings. If transfer trip (communication) is used, then it is not an issue. If not, then it is a challenging for anti-islanding detection with fast reclosing.
4.2.3	Voltage	Available	adjustable set points for DG > 30kW. Could be realized using FlexLogic
4.2.4	Frequency	Available	adjustable set points for DG > 30kW. Could be realized using FlexLogic
4.2.5	Loss of Synchronism	Available	sync check. Also need to monitor flicker. Leave it as DG design issue.
4.2.6	Reconnection to Area EPS	Available	The delay time should be user adjustable.
4.3	***Power Quality***		
4.3.1	Limitation of DC injection	N/A	UI could monitor it, but too costly. Need LEM current sensors, not just CTs, if want to monitor it. Leave it as DG design requirement.
4.3.2	Limitation of Flicker Induced by the DR	N/A	Monitoring flicker, SMARFI 90, 80, 70
4.3.3	Harmonics	N/A	UI could monitor it, but too costly. To monitor harmonics (up to 40th harmonic), may need additional computation resources. Leave it as DG design issue.
4.4	***Islanding***		
4.4.1	Unintentional islanding	*Anti-Islanding protection*	detection within 2s.
4.4.2	Intentional islanding	N/A	no requirements given yet in the standard

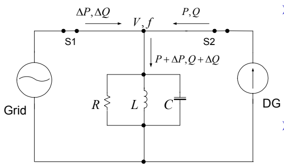
- Anti-Islanding (AI) is the Key function for UI development

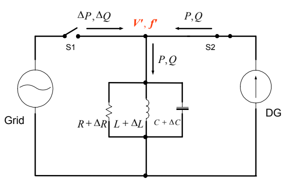
Anti-Islanding (AI) Schemes

- **Local sensing (Relay Function)**
  - U/O V&F
  - Vector Shift
  - ROCOF, …
- **Perturbation**
  - Impedance monitoring (ENS)
  - Impedance insertion, …
- **System coordinated control**
  - Transfer trip
  - Communications, …
- **Integrate with DG control**
  - SFS, SVS
  - SMS
  - Asymmetrical Wave, …

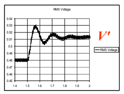
- **No single optimal scheme in terms of cost, technology neutral, effectiveness**
- **Local sensing is much better-off in terms of UI implementation**

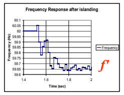
Non-Detection Zone (NDZ) Study

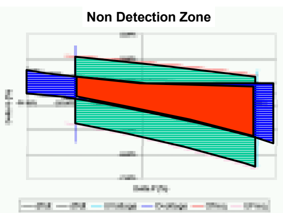




- **AI Performance Index: Non-Detection Zone (NDZ), defined as the region (in ΔP, ΔQ space), within which the DG or interconnection devices cannot detect an island.**
- **Better understanding of dominant factors that influence anti-islanding protection.**



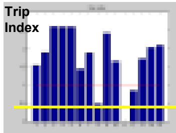




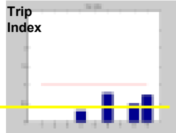
- **The combined anti-islanding schemes lead to reduced NDZ**
- **Green: Under/Over Voltage/Frequency**
- **Blue: Rate Of Change Of Frequency (ROCOF)**
- **Red: Combined Scheme with Reduced NDZ**

AI Setting Study

- **A typical distribution system used to simulate islanding and disturbance cases**
- **Trip index is a function of AI algorithm and system parameters**
- **First trip index threshold (red line): All disturbance cases are bypassed, however, 3 actual islanding cases are missed**
- **Lower trip index threshold (yellow line) can better capture islanding, but also subject to nuisance trip**



15 islanding cases



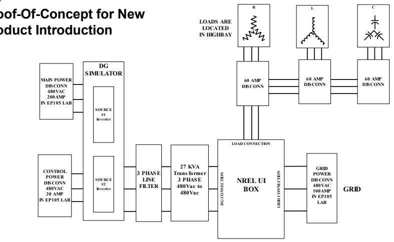
9 disturbance cases

UI Prototyping and Testing

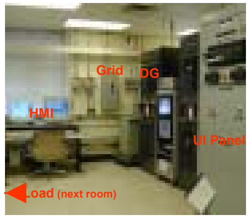
Testing Diagram

Objectives:

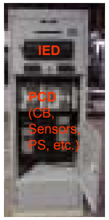
- **Validate NDZ**
- **Optimize AI Settings**
- **Explore Practical Issues**
- **Proof-Of-Concept for New Product Introduction**

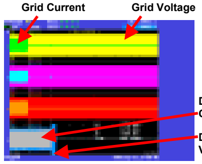


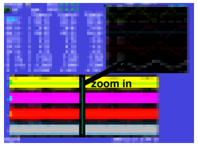
Testing Facility



UI Panel





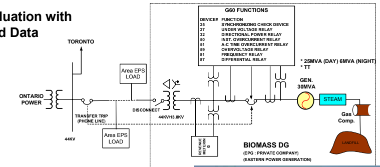


- **Trip O/F after 1.5 sec**
- **ΔP=0.5%, ΔQ=11%**

- **No trip**
- **ΔP=0.0%, ΔQ=0.7%**

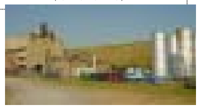
Test Site – A Biomass DG

- **Evaluation with Field Data**



Disturbance

Islanding

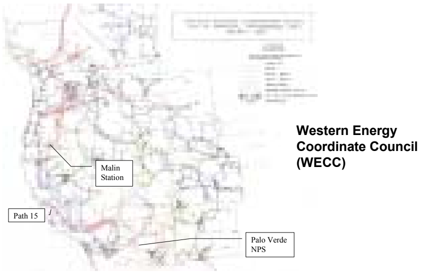


DG Penetration Study

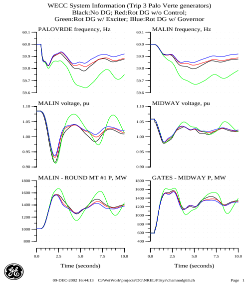
Objectives

- **Provide quantitative insight into the critical issues**
- **Results are useful to the industry in defining interconnection standards**
- **Focus on both near term reality and longer term high penetration**

A Bulk Power System (WECC)



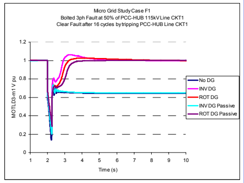
Western Energy Coordinate Council (WECC)



- **Event: Trip 3 Palo Verte Generators**
- **Black: No DG**
- **Red: DG w/o Control**
- **Green: DG w/ Exciter Control**
- **Blue: DG w/ Governor Control**
- **One interesting result: controlling voltage, without controlling frequency can adversely effect system performance (for a capacity event)**

Microgrid Study

- **Event: a non-islanding grid disturbance**
- **Active control of DGs within a microgrid can benefit both the microgrid and the host grid.**
- **No DG case fails - bad for microgrid and host grid**
- **Rotating DG tends to have some inherent benefits**
- **Inverter DG less inherent response, but faster when controlled**



Future work

- **Continue combined passive anti-islanding study and testing**
- **Explore active anti-islanding implementation and testing issues**
- **Study active anti-islanding for machine DG**
- **Explore interconnection issues for facility microgrid**
- **Support P1547.x standards development**
- **…**